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Project director(s):
COLLARD D M CHEMISTRY (404)894-4002

Sponsor/division names: AMERICAN CHEMICAL SOCIETY / POLYMER EDUCATION COMMITTEE
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PROJECT ADMINISTRATION DATA

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Security class (U,C,S,TS) : U ONR resident rep. is ACO (Y/N): N
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Georgia Institute of Technology
Office of Contract Administration
PROJECT CLOSEOUT - NOTICE

19-DEC-1997 10:30

Closeout Notice Date 19-DEC-1997

Project Number G-33-565

Doch Id 35361

Center Number 10/11-6-P5325-0A0

Project Director COLLARD, DAVID

Project Unit CHEMISTRY

Sponsor AMERICAN CHEMICAL SOCIETY/POLYMER EDUCATION COMMITTEE

Division Id 5952

Contract Number LTR DTD 940610

Contract Entity GTRC

Prime Contract Number

Title A PRECOLLEGE POLYMER EDUCATION PROGRAM

Effective Completion Date 30-SEP-1996 (Performance) 30-SEP-1996 (Reports)

Closeout Action:	Y/N	Date Submitted
Final Invoice or Copy of Final Invoice	N	
Final Report of Inventions and/or Subcontracts	N	
Government Property Inventory and Related Certificate	N	
Classified Material Certificate	N	
Release and Assignment	N	
Other	N	

Comments

Distribution Required:	
Project Director/Principal Investigator	Y
Research Administrative Network	Y
Accounting	Y
Research Security Department	N
Reports Coordinator	Y
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Georgia Tech Research Corporation	Y
Project File	Y

G.33.565

"A Precollege Education Program in Polymers"

Annual Report, March 1995
PolyEd Curriculum Development Award, 1994

David M. Collard
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Georgia Institute of Technology
Atlanta, GA 30332-0400

Summary.

The Georgia Tech precollege polymer education program has two main thrusts: development of a demonstration and workshop outreach program, and production of displays and interactive exhibits of polymers suitable for museum settings. In the last six months undergraduates have developed a polymer outreach program for presentation in classrooms and at science museums. The program has been presented twice, and we have a full schedule of offerings in April and May. We have advertised the outreach program by presentations to k-12 teachers, distribution of a flier, and poster presentations at conferences. We have assembled two polymer-related display case exhibits and an interactive liquid crystal display. In the next year we will further develop the outreach program, work with science museums, and continue development of interactive displays.

In the original proposal we set out our plans to develop and implement a broad-ranging program of outreach opportunities in polymer education, primarily aimed at k-12 students. The aim of this program is to introduce young audiences to the role of polymers in society, to excite their curiosity, and to develop an understanding of their relationship to polymers in their food, health, shelter, transportation and entertainment. This program would serve the community, with participation of colleges, school systems, museums, professional chemists and civic organizations. One of the most important aspects of the proposed program will be the participation of Georgia Tech undergraduates (through the

American Chemical Society student affiliate group) to develop and present demonstrations and to work as museum interpreters. This Atlanta-based program will serve as a role model for similar programs elsewhere. The following list of activities have been undertaken in the first six months of the project (September 1994-February 1995).

* *Six students have been recruited to work on various aspects of the project.*
Two students, Scott McKee (junior) and Katrina Ford (senior) have developed demonstration experiments and scripted a 50 minute presentation. They have been helped during presentations by Jeanette Anderson (sophomore). Ginger Barr, Kelly Casey, and Nikki Phillips (all seniors) have worked on display case presentations. Early in the project, Scott presented a number of experiments at our ACS student affiliate meeting to increase interest. Since the four seniors will graduate in May (two will work for Hoechst Celanese before graduate school, one will attend law school), we need to continue recruitment.

* *Display case presentations of polymers have been constructed.*
In order to develop displays appropriate for adoption at science museums, and to interest the Georgia Tech undergraduate community in polymers, we have filled two large display cases with polymer related materials. Sections include discussion of polymerization chemistry, polymer structure, recycling, and polymers around the household. A third case outlines liquid crystals, with interactive (push button–and–observe) demonstrations of electrochromic and thermochromic materials. The display cases are located outside of large lecture halls where general and organic chemistry are taught. Purchase of the display cases was made possible by an award from the Georgia Tech Center for Education Integrating Science, Mathematics and Computing.

* *A demonstration outreach program has been developed.*
In a 50 minute program, Scott, Katrina and Jeanette present polymer chemistry through the use of models, demonstrations and hands-on activities. Many of these were adopted from resources supplied by John Droske (Stevens Point) and Marie Sherman (St. Louis). We have also edited together some short video clips of polymers in action. Everyone involved in the project is under orders to be on the

lookout for new, perhaps surprising uses of polymers which we can bring to these programs.

* *We have presented the demonstrations on a pilot scale.*

Two presentations were made to approximately 60 eighth and ninth grade students taking part in Georgia Tech's "Futurescape" program which is designed to bring middle and high school female students on campus to learn about science and technology. A number of teachers also attended these presentations and have invited us to their classrooms. The program works well with approximately 30 students, since it gives each participant the opportunity to volunteer to help with demonstrations, and means that hand-on activities can be supervised.

* *We have developed a schedule of demonstration programs for the next academic quarter.*

In April and May the outreach program will be presented at four schools and to more "Futurescape" groups. We also hope to present it at SciTrek, the Science and Technology Museum of Atlanta. At schools, we can schedule two one-hour presentations per week.

* *We have advertised the program at local "Project Chemistry" workshops.*

It is quite clear that many middle school teachers feel ill-equipped, and unprepared to teach science. Many have voiced their frustration, and have been delighted at the idea of the demonstration program. We have also been asked to present a teacher workshop.

* *Undergraduates presented a poster at a regional ACS meeting*

Ginger Barr and Nikki Phillips presented a poster on the proposed programs early in the project at the South East Regional Meeting of the American Chemical Society in Birmingham, Alabama in November 1994. The students made contacts with other Student Affiliate groups and exchanged ideas and recipes. The poster was also presented at the Georgia Tech Polymer Education and Research Center's Polymer Program Associate Meeting in February, where it attracted the attention of industrial sponsors of polymer research on campus.

* *We have attracted matching funds for the project.*

Hoechst Celanese Corporation (David Schiraldi, Polymer Research, Charlotte), and Georgia Tech's Center for Education Integrating Science, Mathematics and Computing have provided matching funds. The undergraduate student government provided matching funds for undergraduates to present the poster in Birmingham.

* *Immediate plans for the next six months include:*

– Further presentation of the outreach program in k-12 classes.
– Presentation of the program at SciTrek.
– Survey of Science museums regarding polymer related displays.
– Further development of interactive displays.
– Development of "Polymers in the Olympics" in time for 1996.
– Scott McKee will be employed full time this summer to work on various aspects of the project

G-33-565
2

POLYMER CHEMISTRY IN SCIENCE MUSEUMS: A SURVEY OF EDUCATIONAL RESOURCES

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Abstract

Although science museums are in a unique position to provide opportunities for informal education, the presentation of chemistry in museums is sparse. The successful presentation of chemistry to the public relies on the development of the relationship between molecular structure and reactivity with familiar materials of recognized value. The suggestion that development of polymer related pedagogical tools for presentation of chemistry in museums is primarily driven by the public's familiarity with plastics, and the availability of a simple model which relates molecular structure to properties. A survey of the use and portrayal of polymers in science museums as educational resources identifies a number of successful programs. The suggestion is made that exhibits concentrating on polymers will serve to present chemistry in a manner which is both entertaining and educational to a broad audience.

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Introduction

Science museums have many unique strengths which position them as key players in educational reform. They can offer experiences to students which are unavailable in the classroom and provide opportunities for informal education. However, the presentation of chemistry in museums is difficult because of the dynamic nature of reactions, consumption of supplies, and issues of waste disposal. The absence of chemistry in science museums has recently been reported as a major concern of the American Chemical Society (ACS).[1] The Association of Science-Technology Centers (ASTC) has summarized the state of the portrayal of chemistry in museums, identified obstacles, made recommendations, and clearly points out deficiencies in the presentation of the chemical sciences.[2] Although a survey of 124 museums in 1990 resulted in a long list of chemistry programs and exhibits, many problems are apparent. The presentation of chemistry through interactive displays is difficult, especially the illustration of "wet" chemistry. There has been a general lack of innovation of new programs or exhibits, with most institutions offering existing programs rather than developing new ones. Few professional chemists are involved with science museums, resources available to museums are restricted, and they are inadequately supplied with books and chemicals. Very few museum staff have training in chemistry.

An ASTC-sponsored conference at the Belmont Center in Maryland in 1990 led to the development of a report with a number of recommendations for science museums.[2] These included the need to make a concerted effort to increase the availability of chemistry exhibits, to provide support to teachers, to insure that chemistry careers are viable choices for all, and to locate funding. Other recommendations included encouragement to agencies to provide funding at a variety of levels, and for chemistry professionals to become more involved with museums. It is unclear whether these have been acted upon since this report was published.

Here we survey the portrayal of polymers in science museums and suggest a series of interactive exhibits for development to promote presentation of chemistry through discussion of reactivity, structure and properties. There is compelling reason to suggest that museum-based educational programs in polymers will serve as a dynamic introduction to chemistry. Polymers can be used as examples of non-toxic chemicals which are safe to handle, and they can be used to introduce the principles of chemistry, physics, biology and engineering. Polymers are all around us, and they are familiar to the public. The molecular structure of polymers can be represented by a number of models which can be explained to museum visitors. A simple model of tangled chains can be used to rationalize the flexibility of plastics, elasticity of rubbers, rigidity of thermosets, and the transparency or translucency of amorphous and crystalline polymers. Outcomes of investigations presented as interactive exhibits can be related to the simple model. Exploration of the model at the atomic scale can be used to further explain the effect of chemical structure on physical properties. In addition to simple models for molecular *structure* of polymers and the relationship to *properties*, the *reactivity* of monomers can be represented by demonstrations of chain and step growth polymerization pathways. Finally, the historical development of polymer science serves as an exceptional example of the interplay between scientific inquiry, commerce and fashion.[3,4]

The Division of Polymer Chemistry of the American Chemical Society has organized a number of "Polymers in Museums" symposia at national meetings. A majority of the presentations[5] discuss the classification, storage and deterioration of plastic artifacts.[6] Only recently has there been discussion of the role that polymers can play in science education within the museum setting.[7] Since very few of the museums surveyed[2] in 1990 identified polymer-related displays and programs, we have undertaken an investigation of the current use and portrayal of polymers in science museums. The survey was supported by the Polymer Education (POLYED) Committee of the American Chemical Society, a joint committee of the ACS divisions of Polymer Chemistry and Polymeric Materials: Science and Engineering. Our interest in the use of polymers in science museums arises not only from the fact that plastics are themselves of scientific interest, but also because they can also be used to demonstrate numerous scientific principles in other fields of study, and to illustrate the scientific method. Exhibitions using polymers could be highly interactive, whereby the direct manipulation of a polymer executes an experiment for direct observation. In addition, demonstration programs and hands-on workshops could provide unique educational experiences for participants.

We developed a ten page survey which was mailed to 243 members of the ASTC (out of a total membership of 355)[8] to explore the use and portrayal of polymers in museums. Discovery centers, children's museums, city, county and state museums, museums of natural history and planetariums were included in this mailing; botanical gardens and aquariums were generally excluded. Specialized museums such as those dedicated to space exploration, transportation, and surgery were also included. These have great potential to provide insight into how polymers are used in very specialized applications. The museums were distributed throughout all 50 states. The survey included a brief overview of the importance of polymers, and was constructed in three parts. The first part requested information about thematic exhibits such as those dealing with transportation, space, health and medicine, communication, history of science, etc. If a museum housed a particular type of exhibit we requested information on the use or discussion of polymers in the exhibit. The second and third parts of the survey requested information about demonstration programs and hands-on workshop programs, respectively. Further analysis of polymers in museums was made through interviews, visits, surveys mailed to ACS student affiliate chapters, and the literature.

The Current Situation

Despite a relatively high rate of return of the surveys (a total of 129 museums were surveyed, similar in sample size to the ASTC survey of chemistry) a statistical analysis of the data is unwarranted: the presentation of polymers in museums is, perhaps not surprisingly, quite lacking. Many of the museums identified polymers in thematic displays, though the materials were rarely discussed in the exhibits. Whereas many museums include molecular models or other representations of the structure of DNA or proteins, they do not present models of synthetic polymers. Even when the long chain structure of polymers is mentioned, it is rarely presented as the origin of plastic's unique combination of properties.

One museum, The National Plastics Center and Museum (NPCM),[9] in Leominster, Massachusetts, is dedicated to the presentation of polymers. Leominster has been a center for plastics manufacturing from the time that the thriving comb industry, established in the town in the eighteenth and nineteenth centuries, switched from animal bone and tortoise shells to celluloid as a raw material. The Viscoloid Corporation was established in the town in 1900 to supply celluloid, and along with companies in Fitchburg and Worcester in central Massachusetts, the area has played an important role in the development of the plastic industry in North America. Visitors to the Leominster museum are greeted in the foyer by a flock of Don Featherstone's polyethylene flamingos produced by Union Products in nearby Fitchburg. The museum occupies 10,000 square feet on two floors of a converted 1900 school building, with plans to renovate another two floors (20,000 square feet) for display space and a library.

An extensive display of plastic medical devices donated by Dow challenges visitors to match a material and its properties (i.e., soft polyolefin plastomers; tough, transparent polycarbonate; and flexible polyurethane elastomers) with various applications (i.e., face masks, cardiotomy reservoirs, and triluman catheters). Themes presented include the use of polymers in reducing medical waste (i.e., use of lightweight PVC collection bags), enhanced design-flexibility (light, maneuverable advanced composite folding wheelchair), and cost effectiveness. The use of plexiglass for intraocular lenses, mylar for space blankets, and polyurethane for the meniscal reconstruction of knee joints, are all justified by matching polymer properties with stringent medicinal requirements such as strength, lifetime and biocompatability.

A number of museums identified exhibits presenting the recycling of plastics. An exhibit at the NPCM supported by Borg Warner and the GE Company dispels many myths about the environmental impact of plastics: that they are the largest component of municipal waste (they actually account for about 20%), that paper grocery bags are more environmentally friendly than paper ones (not so, when considering the use of fossil fuels expended in the manufacture and distribution of bulky paper products), and that elimination of plastic packaging would have a dramatically positive environmental impact (which ignores the recyclability and weight advantages of plastics). Numerous recycled plastic items are displayed.

Historical artifacts in the museum include a number of antique combs, rattles, dolls and housewares manufactured in central Massachusetts. The historical mission of the museum is also manifest in the growing collection of documents. The collection was recently enhanced through the acquisition of materials from the Western Plastics Center. The NPCM also houses the Plastics Hall of Fame with photographs and profiles of the 94 inductees (1973-1994).

Polymer *chemistry* is presented at the museum primarily through demonstration programs in the Plastic Lab. The long chain nature of polymers is explored through these demonstrations, along with the relationship between structure and physical properties. The NPCM offers outreach programs at other museums and trade expositions, and in one of the most far reaching programs, the museum operates two vans (the "PlastiVan") which serves as a mobile classroom and laboratory. The first PlastiVan has made stops at over 30 sites, presenting programs to a combined audience of more than 10,000.

Other touring displays about polymers include the Chemical Heritage Foundation (CHF) "Polymers and People: An Informal History" exhibit, and "Behind the Seams: The Science of Fashion" developed by Discovery Place in Charlotte, North Carolina, with the assistance of employees of Hoechst Celanese Corporation from the company's nearby Dreyfus Research Park.[10] The CHF exhibit consists of twelve panels which explore the history of polymer science, including: early polymer products, the first description of polymers as long chain molecules, advances made during World War II, commercial and environmental issues, a look into the future, and the NPCM. Two booklets which accompany the display outline the history of polymers[11] and the discoverer-inventors.[12]

The Chicago Museum of Science and Industry (MSI) also has extensive discussion of polymers. There are *three* displays of common polymeric items. "Earthtrek", an Amoco-sponsored exhibit about oil exploration and refining, petrochemicals and alternative energy sources, includes a room-sized "Products from Petrochemicals" display of household items with an audio explanation. A similar display in the "Gas Energy" exhibit relates polymers and items to the hydrocarbon gases from which monomers are derived. Polymers appear as part of the organic chemistry exhibit in the Regenstein Hall of Chemistry. A display of polymer rods is accompanied by a list of their uses, which points out the pervasiveness of plastics in society. The display also includes a video produced by Dow profiling Saran products. MSI has one of the largest collections of *interactive* chemistry exhibits. The only polymer-related experiment has polybutadiene and polyisobutylene balls dropping side-by-side, with the explanation that the chains of the former are easily deformed but move back to their original shape providing a bounce, in contrast to the absorption of energy by the "sluggish" chains of the latter.*

Polymers appear at the MSI as part of a number of broad-ranging science exhibits such as the History Wall (Table 1), the National Business Hall of Fame (plaques and video biographies include profiles of Pierre Samuel du Pont, Harvey S. Firestone and Leo S. Bakeland), and the R&D magazine "R&D 100 Awards" exhibit. Polymers even get mentioned in the museum's extensive "Nutrition" exhibit. The role of plastics in food storage is acknowledged: "Polymer chemistry, spurred by the needs of World War II, produced a whole family of plastic packaging materials; thin, strong, flexible and water proof, they make long-term food protection possible". Elsewhere in the museum the development of electronically conductive polyacetylene in Professor MacDiarmid's laboratories at Pennsylvania State University is portrayed in a display case including a menu driven computer presentation. The display discusses the potential for use of conductive polymers in electric cars, lightweight batteries, microchips and solar power devices.

Two large exhibits in the Smithsonian National Museum of American History in Washington, DC, include some discussion of polymers. "Science in American Life"[13] was supported in part by the ACS, but was later the subject of considerable debate regarding the way in which the benefits of science to society are presented.[14] The exhibit includes discussion of Carothers' discoveries, biodegradable polymeric shampoo bottles, and the use of plastics around the house. The museum's "Material World" exhibit includes examples of Bakelite and Kevlar. The museum houses Baekeland's autoclave used for the development of Bakelite.

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* Other interactive experiments include the separation of oil, water, fluorocarbon and mercury; an automated colorimetric titration; chemiluminescence; water electrolysis and ignition of the resulting gasses, and a clock reaction.

The ACS has conferred chemical landmark status on the "Bakelizer", or "Old Faithful", in recognition of its importance in the development of synthetic polymers.[15] Other ACS landmarks include The First Nylon Plant (du Pont, Seaford, Delaware), the Chemicals from Coal Facility (Eastman Chemical Company, Kingsport, Tennessee) and the Sohio Acrylonitrile Facility in Cleveland.

Whereas many of the polymer exhibits outlined above concentrate on physical properties rather than chemistry, programs at a number of museums, including the NPCM and the "Mr. Monomer" demonstration at the Great Lakes Science Center (GLSC, Cleveland, Ohio), incorporate discussion of polymerization reactions and molecular structure. Even when demonstration programs are not offered regularly, many museums host student groups, faculty or industrial chemists to present programs on an occasional basis or during National Chemistry Week. Several museums have hosted demonstration programs incorporating published procedures[16,17] including "slime",[18] the nylon "rope trick"[19] and super-absorbent polymers.[20] However, these are included in broad-ranging chemistry programs rather than in concentrated educational programs in polymers. Although these three demonstrations provide a dramatic introduction to polymers, *they do not present general properties associated with polymers and leave visitors with lasting misconceptions unless the subject is developed extensively.* The fact that demonstrations and hands-on programs are the primary vehicles for treatment of polymer *chemistry* is apparently a result of the real (and possibly) perceived difficulties in presenting chemistry in museums.

Although demonstration programs are labor intensive, visitors to the Ford Motor Company-sponsored "Products Technology" gallery at the GLSC can order up their favorite polymer dish from the museum volunteer at the materials bar: Kevlar-oni pasta, odd-ball olives (black rubber balls), a sodium snowcone (superabsorbant sodium polyacrylate), and saturation soup (dissolving Eco-foam packaging pellets). Nearby the strength of Kevlar and cyanoacrylate polymers ("Super-glue") are explained and dramatically displayed by lifting a compacted car by a lever.

None of the exhibits mentioned so far present the range of polymer properties in such a dramatic fashion of the Polymer Fun Room at GLSC. Children can bounce off vinyl walls, pluck nylon harp strings, drop Tyvek parachutes, jump over squishy foam stepping stones, slide down slippery teflon or sticky rubber ramps, and peer through transparent vinyl windows.

Thematic exhibits which present the opportunity to discuss polymers include transportation, space exploration, health and medicine, and optics. A number of museums have displays of NASA space suits, including institutions specializing in flight and space exploration such as the Virginia Air and Space Museum, Hampton, Virginia (near NASA's Langley facility); the Museum of Flight, Seattle, Washington (with strong ties to Boeing Corp.); the U.S. Space and Rocket Center, Huntsville, Alabama; the Maryland Science Center (the Hubble space telescope visitor center) and the Museum at the NASA Johnson Space Center. Unfortunately none of the displays identified in the survey describe the *materials* used to protect astronauts from the environment of space.

Automotive exhibits with discussion of polymers include demonstrations of safety glass at the Henry Ford Museum (Dearborn, Michigan), and the "Polymers in your Automobile" display at the NPCM consisting of winning entries from the design competition organized by the Detroit section of the Society of Plastics Engineers. The properties for which polymers are chosen for automobile design (strength-to-weight, durability, colorability and processability) can also be related to their use for sports, as mentioned in the "Science of Sports" exhibit developed by Ohio's Center of Science and Industry.

Plastics such as plexiglass are ubiquitous to exhibits on optics, finding use as lenses and prisms. However, the underlying cause of the transparency of this plastic (or of glass) is not mentioned. The effect of the long chain structure of polymers on the propagation of light is profiled at the Exploratorium in San Francisco. The rotation of plane polarized light by oriented chains of cellophane forms the basis for a colorful display set up on an overhead projector.[21] Elsewhere in the optics display the stress induced birefringence of plexiglass is demonstrated.

The number of biochemistry and health-related exhibits in science museums has grown rapidly in the last few years. The discoveries of protein structure and the double helix of DNA are presented as highlights in the history of science (e.g., on the History Wall at MSI). Three-dimensional molecular models of these complex biopolymers are presented at a number of museums along with computer animations allowing for substrate docking in enzyme active sites and DNA fingerprinting. The processes of transcription and translation are performed by visitors at the San Francisco Exploratorium in an interactive exhibit. A double helix of DNA consisting of a sequence of bases represented by metal coupons with different shapes is unwound by the turn of a knob; the visitor builds a complimentary sequence of RNA bases by templating them on the single strand DNA; and finally this RNA serves as a template for construction of the amino acid sequence of collagen.

Science centers are not the only museums to present technical information about polymers. Since 1940 when the New York Museum of Modern Art (MOMA) exhibited molded laminated wood pieces in an Organic Furniture Competition, the use of plastics as media for art and design projects has been the subject of a number of museum exhibits. Recent examples include: "The Plastics Age: From Modernity to Post-Modernity"[22] at the Victoria & Albert Museum and "It's Plastic!"[23] at the Design Museum, in London, and "Mutant Materials in Contemporary Design" at the MOMA. The phrase "mutant plastic" is explained by the statement that "until the middle of this century they [plastics] were used only to imitate natural materials....Today's plastics are sturdy, resistant, and beautiful. They can take on many shapes, from the most straightforward to the most articulated. No form is absolute: mutant plastics can resemble translucent and transparent glass, they can be molded to match the organic shapes of parts of our body, they can be treated to look like folded, articulated plans, and they can be detailed into small, complex objects like computer mouses".[24] Compression molding (described as a "most archaic process"), injection-molding (an example of "more sophisticated technologies"), blow molding, calendering and extrusion, are explained along with the use of recycled materials. The exhibit consists of contemporary designs of a variety of functional items, very few of which would be available to us without synthetic polymers.

Future Possibilities

The survey of museums outlined above clearly indicates a shortage of polymer chemistry exhibits, in common with the dearth of general displays about chemistry. The existing displays successfully relate the wide array of polymeric materials to a diverse set of properties and applications, but molecular reactivity and structure (i.e., chemistry) is rarely cited as the basis for these properties.

The successful presentation of chemistry to the public in museums will rely on the development of the relationship between molecular structure and reactivity with familiar materials of recognized value. The value of plastics to society is clear and simple to demonstrate in a thought-provoking fashion: many objects would not be available without plastics, others would be inferior if constructed from alternative materials. Demonstration of polymer properties with which the visitor is already familiar can be used to promote questions which relate to the molecular scale: why is rubber elastic, why is plexiglass transparent, why is Kevlar so strong? Simple models for the molecular structure of polymers are easy to present, and the microscopic (i.e., molecular) behavior of these models is easily related to familiar macroscopic properties. Manipulation of the tangled chains of beads on a string can be related to the flexibility and strength of thermoplastics. If the model chains are crosslinked they can no longer slip past each other and the model can be related to a rigid thermoset. Packing of chains into crystalline domains can be correlated with the translucency of semicrystalline polymers, and the effect of stretched films of polymer on plane polarized light provides a colorful demonstration to relate the orientation of polymers to the alignment of chains in the model. A more detailed analysis of molecular structure would analyze molecular models (i.e., ball and stick) of repeat units: the rigidity of polystyrene relative to polypropylene can be ascribed to hinderance of rotation about the polymer backbone by the bulky phenyl substituent. Reactivity of small molecules and the preparation of long chains by either chain or step growth processes is easy to demonstrate with a display which mechanically links together "divalent units" which mimic monomers. Table 2 outlines a number of exhibits which challenge the viewer to correlate structure with properties. Some of the experiments already appear in exhibits, others work well in demonstrations and are amenable to presentation as interactive displays.

The suggestion that development of polymer related pedagogical tools for presentation of chemistry in museums is primarily driven by the public's familiarity with plastics, and the availability of simple models which relate molecular structure to properties. The recommendations of the ASTC in 1990 to enhance the presentation of chemistry in science museums are still valid; production of new, exciting and interactive programs will rely on both investment and the development of creative teams with educational, technical and artistic expertise. Adopting successful aspects of existing programs, and development of exhibits concentrating on polymers will serve to present chemistry in a manner which is both entertaining and educational.

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Table 1. Polymer Chemistry on the History Wall: Landmarks in Modern Science" at the Museum of Science and Industry, Chicago[a]

Improving on Nature's Rubber	1831-1835	Goodyear's vulcanization of rubber
The First Plastics	1848-1868	Schönbein's fabrication of nitrocellulose (gun cotton) into transparent films for photography; heat molding of celluloid by Hyatt.
Polymer Plastics	1920	Staudinger's description of long chain molecules; styrene, propylene, ethylene
The Art of Artificial Silk, or Birth of the Leisure Suit	1883-	"A centuries old dream was realized in the late 19th century with the first completely synthetic fiber"; Carothers' nylon

[a]Other panels deal with protein and DNA structure.

Table 2. Potential for Interactive Polymer Chemistry Exhibits: Relationship of Properties to Simple Models for Polymeric Molecular Structure.

property	feature in model	experiment and observation
Ball-and-stick molecular model		
scale	size	comparison of molecular models (water versus segment of polyethylene)
flexibility/ rigidity	rotation around substituted polymer backbone	restricted rotation about the backbone effects the glass transition temperature
monomer reactivity	formation of bonds between repeat units	dynamic bond making and breaking to demonstrate step growth and chain growth polymerization routes
String of beads		
strength	tangled linear chains	
elasticity	lightly cross-linked chains	comparison of mechanical properties of plastics, elastomers, and thermosets
rigidity	highly cross-linked chains	
transparency/ translucency	chain alignment (in crystallites) and entanglement (in amorphous regions)	(i) comparison of transparent (PMMA, polycarbonate, LDPE, amorphous PET) and translucent polymers (HDPE, crystalline PET)[a]
		(ii) stress induced crystallization
birefringence	chain alignment	(i) oriented tape between crossed polarizers[b]
		(ii) stress induced birefringence[b]
density	effect of branching on chain packing	comparison of density of LDPE and HDPE by floatation
heat capacity		comparison of temperature and feel of metal, wood and plastic[b]
electrical conductivity	movement of electrons	completion of electrical circuit to light a bulb with insulating plastic, metal and conductive polymer[c]

[a]PMMA, poly(methyl methacrylate); HDPE, high density polyethylene; LDPE, low density polyethylene; PET, polyethylene terephthalate. [b]Exploratorium, San Francisco. [c]MSI, Chicago